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Thames Tunnel Evidence Assessment

Final Report

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Executive Summary

Defra is responsible for all aspects of water policy; including the quality of water in rivers and sewage collection and treatment in England. In 1991, the European Union (EU) agreed an Urban Waste Water Treatment Directive (UWWTD) designed to protect the environment from pollution from untreated sewage[1]. For over ten years a range of organisations have been investigating how water quality in the Thames Tideway can be improved by dealing with the discharge of untreated sewage into the river through producing and reviewing evidence on the problem and potential solutions. The purpose of this report is to assess whether this evidence is comprehensive, uses appropriate scientific standards and methods and is verifiable. The assessment is designed to enable current and future users of the body of evidence to share an understanding of the 'fitness for purpose' of the many studies and reviews on this topic.

London's largely Victorian sewerage network includes 57 combined sewer overflows that discharge to, or affect, the tidal Thames. They are designed to discharge during storm rainfall to avoid sewage flooding and to prevent the sewage treatment works from being overloaded. However, the system itself is now overloaded and discharges untreated sewage into the Thames on average more than once a week in large volumes, sometimes over one million cubic metres of sewage. Thames Water Utilities Ltd. (TWUL) is the commercial company that provides water and sewage services to its customers. TWUL set up the Thames Tideway Strategic Study (TTSS) in 2001. This was followed by the other studies assessed in this report. In 2006, the Government instructed TWUL to proceed with developing both the potential tunnel solutions identified in these reports. This 'in principle' direction from Government was re-confirmed by the new administration in Written Ministerial Statements in September 2010 and November 2011[2].

The Government has proceeded with the planning framework for the Thames Tunnel through a National Planning Statement which was laid before Parliament on 9th February 2012. In the meantime, the Court of Justice of the EU is considering a case brought by the European Commission against the UK Government for alleged breaches of the UWWTD. On 26th January 2012 the Advocate General gave his opinion that the UK has failed to comply with the Directive in parts of London because *"under Article 10 of Directive 91/271, a failure to treat waste water is permissible only where circumstances obtain which are out of the ordinary."*(p.6)[3] A judgment in the case is expected in 3 to 6 months.

[1] For inland and estuarine discharges, the UWWTD requires that sewage is collected from populations above 2,000 for treatment before discharge to the environment. The Directive acknowledges that it is not possible in practice to construct collecting and treatment systems to handle flows in all circumstances but requires Member States to limit pollution from such overflows.
[2] Hansard Official report of the House of Commons, column 41WS. 10th November 2011.
[3] Court of Justice of the European Union. Opinion of Advocate General Mengozzi.26th January 2012. C301-10.

The method used to assess the Thames Tunnel evidence is based on the Rapid Evidence Assessment (REA)[4] approach. The assessment concentrated on providing a comprehensive and critical assessment of the whole evidence base, rather than evaluating the quality of each specific evidence item. This has involved producing an annotated listing of sources of evidence and using independently verified criteria to evaluate the sources of evidence. The criteria were developed following Government Office for Science[5] and academic research quality guidelines and verified by Defra's Chief Scientific Adviser.

The listing is the source for the detailed assessment of the evidence base for the Thames Tunnel. Finally, the detailed assessment is drawn together to produce overall conclusions by reviewing the extent to which the whole evidence base complies with the high level question devised for this REA:

> *"Is the evidence comprehensive; does it use appropriate scientific standards and methods and is it verifiable?"*

The Thames Tunnel evidence bases focuses on a number of key aspects:

- the nature of the pollution,
- the impacts of that pollution,
- the potential effect of various solutions, and
- assessing the costs and benefits of proposed solutions.

There are 34 reports included in this assessment. The detailed assessment shows that an extensive range of evidence has been collected to gain an understanding of the specific nature of pollution in the Thames; to describe its impact on the local environment and human activities and to evaluate the costs and benefits of a range of solutions.

The evidence base is comprehensive in that it provides sufficient coverage of the issues identified as relevant in the original TTSS and has generally proved adequate to address questions that have arisen during further development of possible solutions. In general the evidence has been produced using appropriate scientific standards and methodologies and in nearly all cases these have been fully explained in published documents so they can be verified. Also, full information is given about the credentials of researchers and the organisations that employ them and on the commissioning relationship with the research studies' funders.

Many studies were overseen by expert steering or advisory groups involving representatives from outside the commissioning bodies for those studies. There are only a few examples where the evidence has not been produced according to these standards, for example where appendices referred to in publications have not themselves been published and where full references are not provided. These limited shortfalls in the evidence base

[4] Magenta Book. Second edition (2011) Her Majesty's Treasury. pp.60-64.
[5] "*The Government Chief Scientific Adviser's Guidelines on the Use of Science and Engineering Advice in Policy Making"* (2010) Department for Business, Innovation and Skills. www.bis.gov.uk

could easily be corrected if required and do not fundamentally affect the wider conclusions that can be drawn from those studies.

Background

Defra is responsible for all aspects of water policy including the regulatory system for the water environment and the water industry; this includes the quality of water in rivers and sewage collection and treatment in England. For over ten years a range of organisations have been investigating how water quality in the tidal reaches of the Thames (referred to as the Thames Tideway) can be improved by dealing with the discharge of untreated sewage into the river. This work has involved producing and reviewing a large volume of evidence on the problem and potential solutions. The purpose of this report is to assess whether this evidence is comprehensive, uses appropriate scientific standards and methods and is verifiable. The assessment has been conducted within Defra in the context of a complex and dynamic policy area, so it has been undertaken alongside but separate from the policy team by a Senior Principal Research Officer. The assessment is designed to enable current and future users of the body of evidence to share an understanding of the 'fitness for purpose' of the many studies and reviews that have been undertaken during the process of seeking a solution to pollution in the Thames Tideway.

Water quality is governed by UK and European legislation. The 1991 Water Industry Act was put in place to provide, improve and extend the public sewers system and to deal with their contents. The UK Water Resources Act was instituted in the same year to regulate discharges to controlled waters to avoid pollution. This Act also put the regional water companies in to the private sector and set up the regulatory framework, specifying roles for the Environment Agency (EA), the Water Services Regulation Authority (Ofwat) and the relevant government department (at that time the Department of the Environment). Also in 1991 the European Union (EU) agreed an Urban Waste Water Treatment Directive (UWWTD).This is designed to protect the environment from the adverse affects of untreated sewage and, for inland and estuarine discharges, requires that sewage is collected from populations above 2,000 for treatment before discharge to the environment. The Directive requires Member States to limit pollution from the use of overflows. The Directive acknowledges that it is not possible in practice to construct collecting and treatment systems to handle flows in all circumstances but requires Member States to limit pollution from such overflows. The UK has also committed to the EU Water Framework Directive (WFD) objective of reaching good chemical and ecological standards in all its inland and coastal waters by 2015. Article 10 of the WFD cites the UWWTD requirements as providing a significant contribution to water protection.

London's sewage network is based on a Victorian combined sewerage network designed to deal with both waste water from premises and rainfall runoff. Integral to its combined sewerage are 57 combined sewer overflows (CSOs), most of which discharge at points along the Tideway from Hammersmith to Beckton and two discharge to the River Lee at Wick Lane and from Abbey Mills (via Channelsea Creek). They are designed to discharge

during heavy storm rainfall to avoid sewage flooding of properties and streets and to prevent sewage treatment works from being overloaded. More modern systems that exist in other parts of the country are based on a separate drainage system design. Although the rainwater dilutes the sewage somewhat in a combined system, when there is a heavy storm the biggest CSO discharges arise from pumping stations which then discharge the excess into the river. Furthermore, due to increased population and number of households, and the increase in impermeably surfaced areas, the system is frequently overloaded. Each CSO can discharge untreated sewage into the Thames on average more than once a week in large volumes; on occasions in excess of one million cubic metres of sewage enters the Tideway.

Thames Water Utilities Ltd. (TWUL, owned by Kemble Water) is the commercial company that provides water to 8.7 million customers and sewerage services to 13.8 million customers in London, across the Thames Valley and South of England. TWUL set up the Thames Tideway Strategic Study in 2001, initially as a three year project, to assess the environmental impact of storm discharges, identify objectives for improvement and propose solutions, together with their benefits and costs. The Foreword to the Steering Group report [29] explains that the study was extended beyond three years to ensure that the reports were robust and held up to full scrutiny. Professor Chris Binnie, who chaired the Steering Group, states in the Foreword that: *"I am satisfied that, based on the original remit of the Thames Tideway Strategic Study, this has been achieved and that a 35km long storage-and-transfer tunnel is the preferred solution out of the many considered".* (p.4). Ofwat commissioned Jacobs Babtie to review the TTSS's work [27] and concluded that a further option of two short tunnels to the east and west would be sufficient to deal with the pollution problem on the basis of their revision of the TTSS objectives. However, the Regulatory Impact Assessment (RIA), produced by Defra in 2007 [16], rejected the Babtie solution as it did not meet the requirements of the UWWTD and the environmental targets on which it was based would not meet future considerations (pp. 17-18).

As the London Boroughs most likely to be affected by the construction of the Thames Tunnel, Hammersmith and Fulham, Kensington and Chelsea, Richmond upon Thames, Southwark and Tower Hamlets sponsored an independent study to review the various options that had been put forward to deal with pollution of the Thames from waste water. A Thames Tunnel Commission was formed, chaired by Lord Selbourne, and serviced by the London Borough of Hammersmith and Fulham. Evidence was taken over three months, including 40 written submissions, and 25 individuals gave oral evidence at three days of hearings. The report was published in October 2011. One extensive evidence report prepared as part of this review was prepared by Professor Binnie, which focused on the project justification for the east and west two tunnel solution.

In 2006, the Government instructed TWUL to proceed with developing, assessing and costing both the tunnel solutions identified by the TTSS and, in further correspondence, in 2007 gave the then Minister's opinion that a full length tunnel is needed to fulfil the UK's obligations under the UWWTD and *"to provide London with a river fit for the 21st century"*

[10]. This was an 'in principle' view which enabled TWUL to continue with the Thames Tunnel project and it was re-confirmed by the new administration in Written Ministerial Statements in September 2010 and November 2011[6]. The Environment Agency also provided Government with a 'position statement' in May 2010 confirming the Agency's continued strategic support for the delivery of the Thames Tunnel.

The Government has proceeded with the planning framework for the Thames Tunnel through preparation of and consultation on a National Planning Statement which was laid before Parliament on 9th February 2012. In the meantime the Court of Justice of the European Union is considering a case brought by the European Commission against the UK Government for alleged breaches of the UWWTD. On 26th January 2012 the Advocate General gave his opinion that the UK has failed to comply with the Directive in parts of London because *"under Article 10 of Directive 91/271, a failure to treat waste water is permissible only where circumstances obtain which are out of the ordinary."*(p.6)[7] A judgment in the case is expected in 3 to 6 months.

Method

The method used to undertake this exercise is based on the Rapid Evidence Assessment (REA) approach, recommended in the official *Magenta Book: Guidance for Evaluation*[8]. This is a pared down version of a systematic review which can undertaken much more quickly and with a lighter touch but follows the general principles designed to assess what is already known about a particular topic. This use of this method was approved by the Cross-government Programme Board (CGPB), which is overseeing the whole Thames Tunnel programme of work and involves a range of stakeholders led by Defra.

The method used in this project continued to evolve because it was undertaken in the dynamic environment of ongoing policy development. The initial scope for the assessment was revised in consultation with the CGPB in December, so that it concentrates on providing a comprehensive and critical assessment of the whole evidence base, rather than attempting to evaluate the quality of each specific evidence item. The evidence assessment has included four short phases: familiarisation and information gathering, developing criteria and producing the annotated listing, writing up the report and documentation, testing the material with CGPB stakeholders and final communications.

The volume of material to be assessed and the limited time available has necessitated that the phases should overlap. Consequently, the project began with a detailed keyword search conducted by the Defra's research library service which did not reveal any significant new material in November, but information gathering has continued throughout the project's ten weeks duration and the evidence listing was only completed finally at the end.

[6] Hansard Official report of the House of Commons, column 41WS. 10th November 2011.
[7] Court of Justice of the European Union. Opinion of Advocate General Mengozzi. 26th January 2012. C301-10.
[8] "*Magenta Book: Guide for Evaluation"*. Second edition (2011) Her Majesty's Treasury. pp.60-64.

This REA has involved producing an annotated listing of sources of evidence produced by Defra, TWUL and others to develop solutions to the Tideway discharge problems and uses independently verified criteria to assess the evidence standards for each item of evidence. The listing collates and references all the available material, provides short descriptions of each evidence item and an assessment of the standards employed in the production of that evidence.

The criteria used to evaluate the sources of evidence have been agreed with Defra's Chief Scientific Adviser and were developed following Government Office for Science[9] and academic research quality guidelines. These criteria were:

i) The extent of peer review;
ii) whether and where the evidence was published;
iii) the authors'/researchers' credentials; and
iv) the source of funding for producing the evidence.

The initial assessment of each evidence item is noted next to each item in the listing provided in the Annex. This listing is the source for the detailed assessment of the evidence base for the Thames Tunnel.

Finally, the detailed assessment is drawn together to produce overall conclusions by reviewing the extent to which the whole evidence base complies with the high level question devised for this REA:

> *"Is the evidence comprehensive; does it use appropriate scientific standards and methods and is it verifiable?"*

Detailed assessment

The Thames Tunnel evidence developed and collected over nearly ten years focuses on a number of key aspects relating to: - the pollution problem in the tidal reaches of the Thames; the impacts of that pollution; the potential effect of various solutions and assessing the costs and benefits of proposed solutions. There are 36 reports included in this assessment – eight of these were produced by the original Thames Tideway Strategic Study [28,29,30,31,32,33,34,35] and ten formed the Thames Tideway Tunnel and Treatment – Option Development series [17,18,19,20,21,22,23,24,25,26]. One report was produced on behalf of the Water Services Regulation Authority (Ofwat) [27], three by the Environment Agency [4,5,6] and four by Defra [2,3,7,16]. Three reports included in the assessment come from 'independent' sources [1,8,36], not part of central government or Thames Water Utilities Ltd., although the Thames Tunnel Commission study [8] was supported by a group of London Boroughs. This section describes the evidence that has been produced on broad themes and then assesses it at a high level against the study criteria.

[9] "*The Government Chief Scientific Adviser's Guidelines on the Use of Science and Engineering Advice in Policy Making"* (2010) Department for Business, Innovation and Skills. www.bis.gov.uk

Rainfall and Pollution

Water pollution in the Thames is largely the result of untreated sewage discharged from CSOs and sewage treatment works storm tanks during and following rain storms. The Thames Tideway strategic studies report [29] stated that it is very difficult to measure the levels of pollution caused by CSOs accurately. This is due to the particular characteristics of the tideway; the number of CSOs, all with different flow rates; the volume of waste water produced in the city and its varying constituent parts and the impact of the tide at different times of the year. The Solutions Working Group report from the TTSS [31] contains detailed descriptions of all the methods used to monitor and gauge the impact of rainfall on the operation of CSOs and to sample, survey and estimate the pollution resulting from CSOs during regular but intermittent and occasionally heavy rainfall events.

The rainfall measurements are taken by TWUL, the calculation of pollution impact by the Environment Agency [5] and additional data have been provided by the Met Office [34]. The Solutions Report [31] explained that understanding rainfall patterns is important to setting the objectives for improving water quality in the Thames because "*By considering the process of rainfall generating run-off, which becomes flow in the sewer system and then potentially a polluting overflow to the river, the objective is either to prevent storm water from flowing through the sewerage system into the river or allow the flow to continue but reduce the biological and chemical load in the discharges to an acceptable level" (p.46).* The Objectives Working Group report [34] provided data from observations for discharges from the 5 largest CSOs in 2000-1 and rainfall that resulted in discharges in the summer of 2000. The reports states that:"*the data shows the occurrence of CSO discharges is not unusual and is not confined to periods of intense or exceptional rainfall. On average, discharges from the sewerage network via the CSOs occur about 50-60 times per year, with yearly totals of about 20 million tonnes being discharged*" (p.9).

The Solutions report provided extensive explanation of the methods used to assess the level of pollution and includes reports from 23 relevant technical studies covering topics from underground works to fish studies to legislation and land use studies. A thorough literature search of sources on solutions to water quality problems in other urban cities from throughout the world is also included. The technical studies referred to have been undertaken by a range of commissioned agencies, independent and in-house experts.

Volume 2 of the Objectives Working Party report [35] contains the modelling study, which takes the data from modelling discharges from CSOs. The main indicator of water quality pollution is the level of dissolved oxygen (DO) in the water, which has impact on the ecosystem and the life forms in the river, especially fish; and the presence of pathogens in the water which can affect river users, for example, people engaged in water-based recreation. Minimum standards for DO to ensure fish and other species can live in the river have been set by the Environment Agency as the regulatory body following guidelines to

the Urban Waste Water Regulations[10]. The DO standards are monitored using Automatic Quality Monitoring Systems and standards set in accordance with methods established by the Urban Pollution Management Manual[11]. Sewage derived litter and sewage solids can also be seen in the river and are measured by observation, photographs and sampling [30].

The data gathered from rainfall measurement have been fed into complex hydraulic models which can be used to estimate the maximum flow rates and volumes during storms. "*The required hydraulic capacities have been based upon the output of running 20 years of rainfall data (1208 historic events) through the Infoworks sewerage model and collating the spill volumes and peak flow rates of each tideway CSO*" (p.55) [31]. These models were developed by InfoWorks for Thames Water and are re-run using new data from depth monitors placed throughout the sewage system and specifically at all the 57 CSO points. The Environment Agency has a water quality model, developed for them by the Water Research Centre, to understand the impacts of CSO and sewage treatment works discharges into the river [9]

The Thames Tideway Strategic Study [30] included a detailed assessment which was conducted as part of the study in 2004, of each of the 57 'outfalls' where combined sewers overflow using information from historical records, visual observations and modelling data. 36 of the 57 were found to be unsatisfactory and causing an adverse environmental impact by various combinations of:

- reducing dissolved oxygen levels causing ecological harm, including fish kills;
- creating visually offensive aesthetic conditions on the river and its foreshore by large amounts of sewage solids and sewage-derived litter, grease and scum; and
- increasing health risks to recreational river users by introducing large amounts of pathogenic organisms into the river.

This assessment was reviewed by the Environment Agency in 2006 to look at the aesthetic and health impacts in more detail, which confirmed the numbers and locations of the unsatisfactory CSOs with new data and a more systematic method of defining satisfactory/unsatisfactory levels of pollution. The categorisation of the Tideway CSOs was reviewed by the Environment Agency in 2008 and again in 2011 (using improved data on overflow volumes from Thames Water) to ensure that those causing adverse environmental impacts continue to be properly identified [5]. This information is also reported in the Thames Tunnel Needs Report [9] and the Defra Regulatory Impact Assessment [16].

[10] "*The Urban Waste Water Treatment (England and Wales) Regulations 1994: Working Document for Dischargers and Regulators. A guidance note issued by the Department of the Environment, Transport and the Regions and the Welsh Office"* (1997) Unpublished. Department for the Environment, Transport and the Regions.

[11] "*Urban Pollution Manual"*, 2nd Edition 1998, Foundation for Water Research'.

The evidence on rainfall and pollution described above has been collected as part of the Thames Tideway studies, overseen by steering and advisory groups including representatives from government bodies, such as the Mayor of London's office, Ofwat and the Environment Agency and by specialist water research bodies such as the Water Research Centre and HR Wallingford. The individual studies have not generally been formally peer reviewed by independent experts. All have been published on the relevant Thames Tunnel Consultation, Environment Agency, Ofwat and Defra websites. The methods used are described in the studies; although a number of these descriptions are in Appendices that have not been published on these websites. Information is given about the scientists and research teams that have undertaken the studies and sufficient detail provided to enable the studies to be replicated and verified. None of the studies have been conducted with funds from research councils or academic institutions.

The Impact of Pollution

The deterioration in water quality produced by pollution has various potential and actual impacts on the River Thames which have been studied as part of the Thames Tideway and Tunnel project. These studies have partly been used to identify the nature of impacts from CSO discharges and partly to specify the objectives of improvements to address the pollution caused by CSO discharges. Based on these studies the Thames Tideway Strategic Study Steering Group [29] concluded that these objectives should be to:

- protect the ecology of the Tideway;
- reduce the elevated health risks to river users attributable to storm sewage discharges; and
- reduce the aesthetic pollution by sewage material and sanitary products.

The Health Protection Agency and City of London Port Authority commissioned an independent study of recreational users, which evaluated the health risk to river users from faecal pollution [36]. This study is used as a source by the Thames Tunnel Needs Report [9]. The report was published by the Health Protection Agency. The purpose of the study was to determine whether data from long-term monitoring could provide useful information to users to predict the duration of poor quality water following a high rainfall event that led to CSO spillages. This could be used to protect public health by providing this information to river users.

The study describes how the microbiological quality of the water, determined by using the presence of particular bacteria in the water, is associated with increased health risk to users of contracting infectious diseases for 2 to 4 days after a discharge. The researchers had intended to use a nested case control study to compare recreationists who had experienced illness with those who had not. However, because they were unable to access enough participants to fill the requirements for the comparison groups in such a study, they conducted a standard case control study instead. The identification of health risk 2-4 days after discharge and data about the frequency and location of discharges throughout the

year make it possible to calculate the number of health risk days at particular points in the river. This information is given in Appendix F of the TTSS Cost Benefit Working Group's report [33] and is then used to evaluate potential solutions to reduce river pollution [17].

The other consideration of the health impacts is provided by Paul Simmons for the Environment Agency [4] who conducted an internal review of the Thames Tideway Methodology for Identifying Combined Sewer Overflows as Unsatisfactory. This paper refers to Ministerial statements in 2007 and 2010 which quoted evidence that frequent overflows and large quantities of untreated sewage discharges were causing increased health risks for recreational users and that it was essential to reduce the risk to human health and prevent negative aesthetic impacts.

The Thames Tideway Solutions report [31] described how once sewage treatment works improvements had been made in the 1970s fish began to return to the Thames. *"Fish returned significantly in the 1980s and salmon are now fairly common. Today, except after storm discharges, the water quality has returned to a condition similar to the early nineteenth century. Anglers are seen all along the river at low tide. Eels are now being fished commercially in the Thames estuary and the further extension of fisheries is planned."* (p.24). However, there was also evidence that localised reductions in fish stocks would follow storm events and other measures to improve the level of oxygen in the river (through the use of 'bubblers' etc.) have frequently been employed. Fish health is used as an indicator of an improved river ecosystem and detailed studies of the impact of discharges from CSOs and the sensitivity of particular species are used as an indicator of the viability and sustainability of the whole ecology of the river. Fish trials conducted by Fawler Aquatic Research Limited for the Environment Agency are précised in the Thames Tideway Solutions report [31] – these produced a 'Tideway Fish Risk Model' which was reviewed by consultants Jacobs for Thames Water as part of their Needs report and published as Appendix F [15]. This paper refers to an independent expert review of the FARL fisheries study by Professor Mike Elliot of Hull University which confirms that the TTSG fisheries studies and Tideway Fish Risk Model remain fit for purpose.

Finally, a significant impact of pollution in the Thames Tideway is the presence of sewage material and sanitary products which affect the aesthetic value of the river for residents and river users. The Thames Tideway Objectives report [34] states that: *"It has been calculated that approximately 10,000 tonnes of sewage derived solids (including paper, condoms, faecal material, sanitary towels and syringes) is discharged from the CSOs into the river every year, where it creates offensive slicks of sewage in the water and large deposits of solid material on the foreshore."* (p.12) Jacobs Babtie [27] questioned this estimate. As part of Jacobs Babtie's review the team undertook a tour of the river on one day on the Environment Agency's water quality monitoring launch to observe the slicks and ascertain their composition. The review concluded that although there is impact from sewage solids discharges there should be further analysis of the impact of this before value of the objective of reducing aesthetic pollution is 'proven'.

In response to this the Thames Tideway Tunnel and Treatment option development study [18] reviewed the TTSS's conclusions on objectives for improving water quality and commissioned a group of experts to undertake this exercise. They were Professor David Kay (microbiology/health), Dr Andrew Turnpenny (fisheries), Chris Lane (Health Protection Agency) and Jon Averns (Corporation of London). The group concluded that a descriptive objective of reducing aesthetic pollution to a point where they cease to have a significant adverse effect should remain in the overall improvement objectives and the Environment Agency developed a protocol which weighted the visibility and size of discharges so that the various options to address them could be tested.

The evidence on the impact of pollution is presented in a range of studies and reports, including those undertaken by 'independent experts', albeit commissioned by the Thames Tideway Strategic Study and Thames Tideway and Tunnel Option Development project, funded by Thames Water or by Ofwat, in the case of the Babtie study or the Environment Agency, Health Protection Agency and City of London Port Authority. These studies have been conducted by a number of specialists and experts in human health and fisheries and included a review of the Thames Tideway improvement objectives. Some have been peer reviewed, as with the evidence on rainfall and pollution above, all have been published on the relevant Thames Tunnel Consultation, Environment Agency, Ofwat and Defra websites. The methods used are described in the studies, although a number of these descriptions are in Appendices that have not been published on these websites. Information is given about the scientists and research teams that have undertaken the studies and sufficient detail provided to enable the studies to be replicated and verified. None of the studies have been conducted with funds from research councils or academic institutions.

Potential Solutions

The TTSS and TTTT developed and considered a range of potential solutions to reduce the adverse effects on the tidal waters of the Thames, caused by the discharge of storm sewage from CSOs. These were tested against compliance with DO standards, set by the Environment Agency; the achievement of a reduction in sewage derived litter and the reduction in the number of days when the river is subjected to increased levels of health risk due to pollution from CSO discharges. The solutions were also assessed in terms of feasibility, including costs. This testing required that all the unsatisfactory CSOs are dealt with by a preferred solution, so that all the adverse impacts included in the objectives are addressed. For example, where discharges from CSOs do not cause a dissolved oxygen problem, the aesthetic and health impacts must still be tackled.

The evidence that is used to test the solutions includes simulations of their performance using the Infoworks hydraulic model, which calculate levels of pollution and then the capacity and capability required for solutions to the pollution problem. These models have been updated from the original modelling and compliance report for the TTSS study [19] to the Needs report analysis [9]. Results from this testing are in the TTSS steering group report [30]. These lead to the conclusion that a strategy which intercepts flows before they enter the river, stores the flows and then transfers them to sewage treatment works is the only one which will meet all the objectives of improving river quality. A full description of the derivation of these models is also given in the Needs report [9] and the Solutions [31] report. They were developed for the Environment Agency by the Water Research Centre.

Other information that is fed into these models to simulate the potential impact of various solutions on pollution in the future includes population estimates and climate change predictions. Population statistics are used to take into account the impact of population growth on water quality in the future [19]. The Needs report [9] gives estimated baseline conditions which use a 2021 population figure. This is not referenced, so it is not possible to identify whether this was an up to date estimate when the Needs report was written. However, the London Plan[12] does indicate an expectation that London's population will continue to increase to 2031 with an associated increase in the number of households – both factors which will increase the waste water output to London's sewers. The climate change predictions included in the Needs report [9] are based on UKCIP02[13]. The Needs report [9] notes that further climate change projections were produced in 2009 (UKCP09[14]) but they are not directly comparable with those used by the earlier modelling studies. The main difference in impact on potential discharges from CSOs in the future from the sets of projections is that the later figures show little evidence that rainfall intensity and duration will change. However, it is still anticipated that temperatures will increase, the sea level will increase and winter rain will increase but summer rain decrease.

The Needs report [9] also includes publication of commissioned studies on alternative solutions to the tunnel options. The feasibility of sewer separation [13] was studied by Montgomery Watson Harza (MWH) by conducting a desk-based study of the social impact of construction and operation of separate sewers for storm rainfall and waste water in five study areas and an analysis of means of phasing the project which would need to take place over many years due to the scale and disruption of the proposed works. The TTSS Supplementary Report to Government [28] explained that sewer separation would result in construction work in potentially every road in London and the modification of the drainage system for virtually every property.

[12] "*London Plan: Spatial Development Strategy for Greater London"* (July 2011) Mayor of London/Greater London Authority.
[13] *"UK Climate Change Impacts Programme" (2002)* UK Environmental Change Institute, University of Oxford. www.ukcip.org.uk
[14] "UK Climate Projections" (2009) Defra. www.defra.gov.uk

Another alternative solution (or at least potential reduction in the overall pollution impact) to tunnel options is the introduction of Sustainable Drainage Systems (SuDS) which reduce the amount of waste water entering the sewage system through combinations of source controls, such as green roofs, permeable pavements, detention basins and ponds. A University of Sheffield research team study, published as Annex E [14] to the Needs report describes how these systems might work in 3 sub-catchments of the London Tideway Tunnels catchment. The study concluded that it is technically feasible to use SuDS to reduce CSO spills but spill frequencies would still be likely to occur over 10 times per year. There were also considerable logistical, legal and regulatory impediments to using SuDS for this purpose in the short to medium term.

Further examination of the potential solutions to pollution of the Thames Tideway was undertaken by the Thames Tunnel Commission [8] and published in 2011. The evidence for this review was provided by a range of organisations and individuals who responded to a 'call for evidence' made by the Commission in summer 2011 and from representatives called to the oral hearings. The Panel also reviewed relevant publications and technical studies, including some that considered cases in a number of cities in the USA. The Commission did not consider any new research or evidence, although Professor Chris Binnie, visiting Professor at Kingston University and Professor Colin Green, Professor of water economics at Middlesex University did make proposals for alternative solutions, which were written up by Professor Binnie and published on the London Borough of Hammersmith and Fulham's website [1]. The report considers how the single tunnel solution became the preferred option, summarises the evidence given in writing and at the hearings and reviews alternative solutions. The Commission concluded that a 'mixed solution' should be considered and the full length tunnel re-assessed.

The evidence used to assess the potential solutions to the Thames Tideway pollution problem has been largely produced by Thames Water in their strategic study and option development projects, overseen by steering and advisory groups including representatives from government bodies, such as Ofwat and the Environment Agency and by specialist research bodies such as the Water Research Centre and HR Wallingford. The more recent Needs [9] report is supplemented by studies from commissioned groups of researchers including expert specialists from consultancies and an academic institution. The Thames Tunnel Commission [8] report also used evidence from previous studies and subjected them to scrutiny using the comments of 'witnesses' and the Panel members' conclusions from these. The methods used are fully explained so could be replicated and validated. Some of the data used in modelling are not fully referenced, so cannot be verified e.g. the population statistics, but the general trend projected is supported by other published data. The Commission Panel included experts with relevant knowledge and experience – three from England, one from the USA and one from the Netherlands. The studies have not generally been peer reviewed by independent experts. The studies are all published by Thames Water except for the Thames Tunnel Commission [8] and Binnie [1] reports, which are published by the London Borough of Hammersmith and Fulham.

Assessing costs and benefits of solutions

Having identified potential solutions to the pollution problem in the Thames Tideway, a number of studies have been undertaken to assess the costs and benefits of these solutions, to identify a preferred solution and to undertake an assessment of the impact of that solution. These studies have been undertaken by Thames Water and by Defra during two stages of developing the Thames Tunnel project; firstly, as part of the TTSS Solutions Working Group and Option Development projects and secondly, as part of Defra's role in ensuring compliance with the UWWTD.

Financial cost estimates were first given in the Solutions Group report [31] for the full range of potential solutions to the water pollution problem, giving operating and capital costs at 2002 prices and projected 2010 prices. These are Thames Water's own calculations of the financial costs involved. They include a general contingency of 30% and make no allowance for improvements to dry weather flows or storm flows at sewage treatment works as the solutions are focussed on dealing with CSO discharges and treatment of the intercepted storm flows. An assessment of the overall project risk for each solution was undertaken by a technical review workshop group, using all the information from the technical studies undertaken for this Group's work. The outcome of this risk assessment was that *"The main conclusion being that Solution A is the only feasible approach*:" (p.6) Solution A is described in the report as *"Storage – CSO flows intercepted along the Tideway, stored within a tunnel and pumped out at a controlled rate for treatment."* (p.5)

Once it had been confirmed to Thames Water by the Government that they should pursue development of the two principal tunnel options (Solution A and Solution H, which is described as the *"West London Scheme – initially formulated as the first phase of Option A, it was apparent that works at the western end of the Tideway would be more likely to achieve the greatest benefits from a given level of investment."* (p.5)) [17], the company then produced more detailed capital costs for a range of options for constructing these tunnels [23]. The study undertaken for Thames Water by NERA consulting (a division of Marsh and Mclennan Companies) examined the financial costs and their profile in full detail, including commenting on cost adjustments 'optimism bias'. They used guidance from the Treasury's Green Book[15] to check the Thames Tideway proposal and found that there were no material factors that had been overlooked.

The financial cost information and analysis was used by Defra in its statutory Regulatory Impact Assessment [16] and updated in the most recent Defra costs and benefits analysis [3] which accompanied the latest policy statement on the Thames Tunnel project from Defra [2]. The financial costs of alternative solutions to the tunnel options are also included in the Needs report [9] estimated by consultants commissioned to undertake studies of these.

[15] http://www.hm-treasury.gov.uk/data_greenbook_index.htm

MWH give an estimate of costs for sewer separation [13] and the University of Sheffield an estimate of unit costs for SuDS operations [14].

The main non-financial cost is the environmental cost in terms of global warming due to substantial energy use in constructing and operating the tunnel options. The cost study was conducted by MWH and is reported in the TTSS Cost Benefit report volume 1 [22]. This group included environmental economists from the Environment Agency, Defra, Ofwat, GLA (formerly Southern Water and Atkins), Hyder Consulting, Eftec and the Building Research Establishment. The report acknowledges that: *"Due to a lack of quantitative data some of the environmental costs identified could not be expressed in monetary terms, and as a result are not included in the final cost benefit analysis. The categories omitted are ecology, archaeology and cultural heritage, playing fields, and open spaces, other material resources not covered and bank side recreation."* (p.9). Monetary values were given to the environmental costs of the construction phase by Entec [24] in their report for Thames Water.

The original TTSS studies [30] included evaluation studies of cost/benefit which valued market and non-market financial benefits from implementing solutions to the pollution problem. The studies were overseen by the Cost Benefit Working Group of the TTSS which included officers from Thames Water, Defra, the Environment Agency, Ofwat, Entec and the Greater London Authority who participated in the group in a technical capacity rather than as representatives of their respective organisations. The report from this group [33] included findings from a Stated Preference Survey conducted by Eftec, with fieldwork by MORI; this was updated in a later study, conducted with the research company Accent reported in the TTTT [22] cost benefit report and the full study was also published by Thames Water [25]. The TTSS cost benefit report also includes findings from the Environmental Costs study conducted by MWH [33] which considered the non-market environmental costs attributable to each of the Tideway solution options. A desk based Congestion Costs Study was also undertaken by Cascade consulting as part of this to estimate the financial costs associated with the potential traffic disruption caused by engineering work. Finally, there was a Market Evaluation Study carried out by Eftec to identify the potential market benefits arising from the Tideway Solutions identified. These results of studies are described in detail in the TTTT cost benefit report [22].

The Stated Preference study [25] was conducted by Eftec employing a core study team with academic advisers and overseen by the TTTT Cost Benefit working group. It uses a contingent valuation design to elicit the level of 'willingness to pay' (WTP) for reducing the impacts of discharges from CSOs in the Thames from Thames Water customers. They tested the respondents WTP for three engineering options – a wide tunnel, smaller tunnel and the two tunnel solution. The study followed best practice guideline recommendations for stated preference studies which should involve extensive testing stages for the survey's instruments. The validity of Eftec's methods is provided by NERA [23], where they describe Eftec's research as 'thorough going' and subject to peer review by a group of academic

experts; although from their reading of the expert in these types of studies – a Manual prepared by Bateman *et al*. for the Department of Transport[16], NERA do comment that the 'cautions and caveats' included in this Manual are a legitimate reason for caution in reliance on the stated preference survey's results (p.27).

Finally, the other non-market benefits Entec assessed, as reported in the TTTT cost benefit report [22] included the potentially most significant - the reduction in flood risk, although there is considerable uncertainty about the levels of risk and the values associated with the potential impact. Effects on biodiversity (including fish) were noted as being of minor significance and the impact could not be monetised. There was a potential minor market benefit associated with reduced use of the bubbler and skimmer vessels and chemical dosing of peroxide, currently undertaken to ameliorate the effect of discharges from the CSOs. In many cases Entec were only able to give high, low and median estimates and note the considerable uncertainty associated with all estimates.

Non-financial benefits were measured using information from Thames Water on fish mortality from modelling outputs from the Tideway study [18] and the Fisheries study data described in appendix G to the TTTT Cost Benefit Group report [22], which allowed comparison of predicted DO improvements for each solution. Also, a sewage litter reduction formula which estimates the percentage volume reduction under each solution was used in the WTP study. The report describes how the group concluded that the evidence they required for the cost benefit analysis was complete through the use of an academic expert panel consisting of Professors David Pearce (UCL), Ken Willis (University of Newcastle upon Tyne) and Ian Bateman (UEA).

The Defra Regulatory Impact Assessment (RIA) [16] reviewed the costs and benefits of the different options and conducted an assessment of the costs and benefits, focusing on those for the full tunnel option (incorporating the stretch of the tunnel in the River Lee) seen to be the only option capable of meeting the objectives. The analysis takes into account the agreed sewage treatment works improvements which are being undertaken regardless of the Thames Tunnel development and therefore considers the additional costs and benefits of the options being considered to address discharges from the CSOs. The RIA examines the areas of uncertainty and possible sources of over or under-estimation of benefits. These are taken into account in the Defra high-level calculations provided by Defra in the 2011 costs and benefits update [3] which estimate whole life costs for the tunnel, whole life benefits in terms of present value figures and 2011 prices. This analysis does not take into account any other factors that might incur costs or deliver benefits than those given monetary values in the Thames Water studies. In particular, there is no account made for short-term employment economic growth or regeneration impacts related to construction of the tunnel nor of the impact of non-compliance with the UWWTD or other consequences of

[16] *"Economic Valuation with Stated Preference Techniques – A Manual"* (2002) Bateman et al. Department of Transport. Cited in NERA (2006) [21]

‘doing nothing’, mainly because numerical monetary estimates of these costs and benefits could not be made (p.2).

The evidence on costs and benefits associated with the various solutions and the preferred solution for addressing Thames pollution has been produced by Thames Water based on a number of technical studies which are published on their website. This information has then also been used by Defra in their Regulatory Impact Assessment and uprating of costs and benefits reports. Some of the studies have been peer reviewed and academic experts have been called in to consider the methods employed. The reports also include discussion of sensitivity studies and uncertainties in the estimation of costs and benefits. Defra’s RIA and costs and benefits analyses have been conducted by civil servants with the relevant expertise including professional economists and according to the guidance set out in the Treasury’s Green Book. These reports are published on the Defra website.

Overall conclusions

Assessing the evidence used in developing the solution to pollution in the Thames Tideway has been a difficult and complex task. There are many apparently similar reports, using much of the same research and analysis, collected over more than a decade. Some of the material does not reference underlying sources well and studies are reported in a number of places, making the body of evidence as a whole quite inaccessible for lay and specialist readers alike. The approach taken here is to simplify this picture by focusing upon key evidence issues fundamental to decisions that have been taken in developing the Thames Tunnel project. Rapid Evidence Assessment has provided a systematic approach, making it possible to readily identify the key evidence sources; understand the way in which this evidence has been produced and consider whether it is comprehensive and verifiable. This assessment could be used by whoever might then need to consider whether the evidence overall, or the specific evidence items assessed here, are ‘fit for purpose’. The evidence can now be reviewed more easily to address future issues that will arise during implementation of a workable solution to improving water quality in the river in line with national environmental standards and international obligations.

The detailed assessment shows that an extensive range of evidence has been collected to gain an understanding of the specific nature of pollution in the Thames; to describe its impact on the local environment and on human activities and to evaluate the costs and benefits of a range of solutions. The evidence base is comprehensive in that it provides sufficient coverage of the issues identified as relevant in the original TTSS and has generally proved adequate to address questions that have arisen during further development of possible solutions. In a number of cases this has involved conducting further evidence and analysis work using the original studies and it is important that the data and methods used continue to be kept up to date during the progress of such a long term project. The ongoing nature of the project could also provide an opportunity to improve

and add to the evidence base through new approaches for valuing social impacts[17] more specifically, using the valuation of social costs and benefits which would complement the earlier studies undertaken..

In general, the evidence has been produced using appropriate scientific standards and methods and in nearly all cases these have been fully explained in published documents, which means that they can be verified. Also, full information is given about the credentials of individual scientists and research teams and their employment in consultancies, agencies, academic institutions and other research bodies and on the commissioning relationship with the research studies' funders.

Many studies were overseen by expert steering or advisory groups involving representatives from outside the commissioning bodies for those studies. There are only a few examples where the evidence has not been produced according to these standards, for example, where appendices referred to in publications have not themselves been published and where full references are not provided. These limited shortfalls in the evidence base could easily be corrected if required and do not fundamentally affect the wider conclusions that can be drawn from those studies.

[17] http://www.defra.gov.uk/publications/files/pb13695-paper5-socialimpacts-wellbeing.pdf

Annex: full evidence listing

Full listing documents included in assessment with initial assessment against criteria and references.